Central Venous Pressure Monitoring:
Misinterpretation, Abuses, Indications and a New Technic

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THE COMPARISON of central venous pressure (CVP) and pulmonary artery pressure (PAP) is often based upon their indications, technics of insertion, attributes and complications.

Much controversy still exists as to the best method of performing these procedures, their interpretation and relative value. This report reviews the basic physiology involved and presents our CVP method as well as the best procedure to evaluate the numbers obtained.

Aubaniac [1] in 1952 first advocated the injection of fluids through the subclavian vessels. Later Keeri-Szanto [4] in 1956 advocated the subclavian vein for intravenous injection. Wilson [6] first popularized this method in the United States in 1962. Since then its popularity has progressively increased. With this popularity much benefit and some abuse of the technic has resulted. We adopted the technic of Yoffa [8] as described in 1965 and have used this supraclavicular procedure since. This method which has been attempted in 3,000 (Table 1), with a success rate of 95%, has been associated with a major complication rate of 1.2% and a single mortality.

The circulatory dynamics of a patient are maintained by the triad of vascular capacitance, effective circulating volume, and cardiac pump action. These three procedures interact to provide blood pressure, cardiac output and tissue perfusion. Central venous pressure must be taken as one parameter by which the interaction of these modalities is evaluated. In the dynamic situation, blood volume determinations by radioisotopes have been found lacking.[7] CVP will be helpful in determining volume needs only if the assumption is valid that both ventricles are functioning with equal efficiency. When this premise breaks down, central venous pressure is not an accurate reflection of needed volume.

Technic

The technic we use for supraclavicular insertion is detailed below. The patient is placed in the semi-Trendelenberg position and the feet are well elevated. The area in the supraclavicular site to be used is selected (Fig. 1). Pillows are removed from under the patient's head. The patient is asked to raise his head from the bed to delineate the junction of the lateral border of the sternocleidomastoid (SCM) and the clavicle. After this is done, the patient's head is turned to the side opposite the proposed area of insertion. The next maneuver is to prepare the supraclavicular fossa in a sterile fashion including the suprasternal notch. Alcohol and iodine are then applied. Sterile towels cover the bed, the patient's anterior chest and the lateral side of the

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TABLE 1. *Supraclavicular Technic Statistics* (1965–1971)

	No.	%
Attempts	3,000	84.1
Successful	2,851	95
Complications	337	11.2
Major % of attempts	36	1.2
Minor % of attempts	301	10.0
Major % of complications	36/337	10.6
Minor % of complications	301/337	89.4

This shows our experience with the supraclavicular method. There has been one mortality from this technic.

patient's head, but not the patient's face. The suprasternal notch should remain in the field as a guide and landmark. A local anesthetic is drawn up in a 10 cc. syringe and is injected. A standard large Bardic Intra-Cath * with a 14-gauge needle is the best

* C. R. Bard, Inc., Murray Hill, New Jersey.

FIG. 1. The clavicle, the sternocleidomastoid muscle and the puncture site are demonstrated from the position above the patient that the operator assumes.

unit to use. This is packaged in a kit containing the necessary parts. The needle is then changed to the 14-gauge CVP needle and the sternocleidomastoid, clavicular angle is bisected. The initial angle begins approximately 10 degrees below the horizontal plane (Fig. 2). After each pass the barrel of the syringe is elevated a few degrees toward the horizontal plane. Most punctures are successful between 10 to 20 degrees above the horizontal plane. Each passage of the needle is preceded by a subcutaneous ejection of anesthetic solution to dislodge any skin or fat bodies impacted in the needle during its insertion. Each attempt is made slowly with gentle aspiration applied continuously with occasional injection of anesthetic to clear the needle of debris. If the first pass is unsuccessful, subsequent attempts are performed by bringing the needle to a subcutaneous position and re-entering at a new angle. The barrel of the needle is maintained in the same axis during a pass. This insertion is slowly performed with aspiration and injection being carried out alternately until the needle is at its full depth. Arterial pressure will cause the syringe to fill without aspiration. The sudden "flashback" of blood is typical of the venous cannulation. Following this, the catheter which has been left in its plastic envelop is placed into the needle barrel after the needle has been grasped with a hemostat to hold its position (Fig. 3). If there is difficulty threading the needle, the bore should be rotated so that the level is down. Initial insertion is with the bevel up. If difficulty persists in threading the catheter, it is wise to remove it if there is no resistance to withdrawal. The needle is then repositioned. If the catheter is difficult to withdraw, it is best to pull out the needle and the catheter or advance the catheter and try to withdraw it again with a rotary motion. If this fails it is best to withdraw both needle and catheter. If the catheter can be successfully withdrawn, the vessel is again aspirated to be sure that the needle remains in the lumen and the angle of the needle is changed while aspirating blood from the vein. Very often this maneuver will allow the catheter to be passed following reinsertion. At this point extreme care must be taken to prevent a catheter embolus. Explanation of the phenomenon is that the vessel is either over-penetrated or under-penetrated and the catheter is tangentially inserted into the adventitial tissue rather than into the vessel itself. The other situation is where the catheter impinges on the opposite wall of the vein instead of following the blood flow.

The last maneuver after taping down the catheter is to aspirate through a venous-connecting tube to be sure that blood reflux is forthcoming. This is a rule which must not be violated. As soon as the catheter is in place the assistant puts his finger over the entry point of the catheter into the skin. Following this maneuver, tincture of benzoin solution is applied over the entire area. Chevrons of ½″ tape are carefully placed to within 1 cm. of the catheter entrance into the skin. Following placement of these tapes, 1 inch tape is used to connect the catheter, the needle, the needle guard, and the hub of the catheter in one

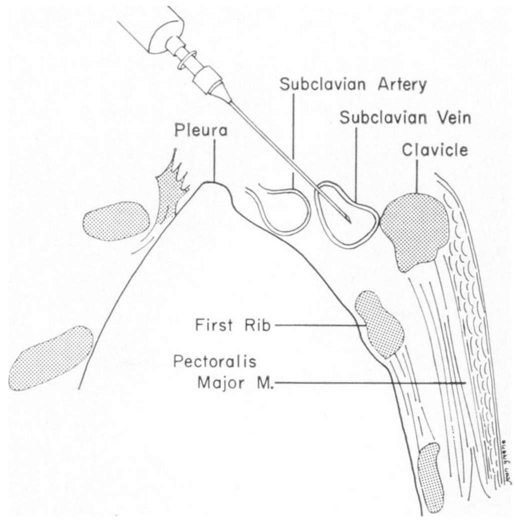

FIG. 2. Demonstration of the angle of the needle during insertion. Cross section of the surrounding structures is shown.

unit and a venous connecting tube is inserted in the line and secured. This prevents detachment with hemorrhage or air aspiration. The catheter is then taped in place and brought back over the patient's shoulder so that he may be ambulatory and have full mobility.

If bleeding should occur because of a hemorrhagic diathesis, pressure is applied

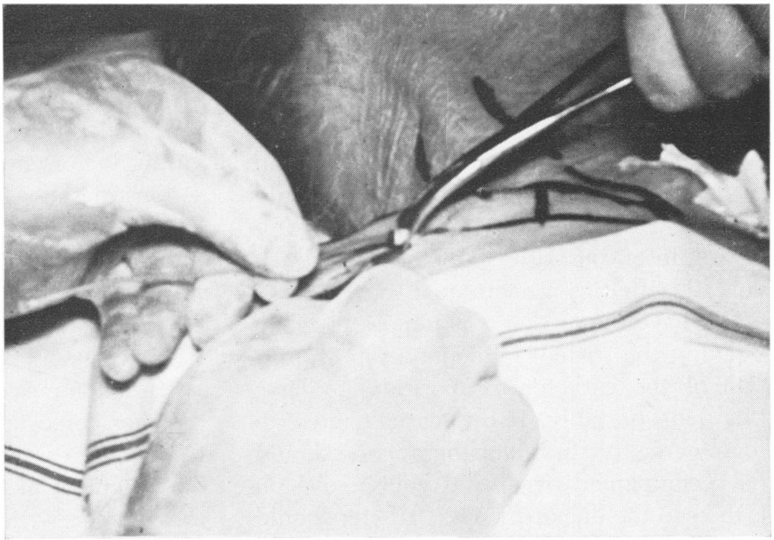

FIG. 3. Assistant performs a critical maneuver postvenous puncture by stabilizing needle in vein with hemostat while catheter is inserted.

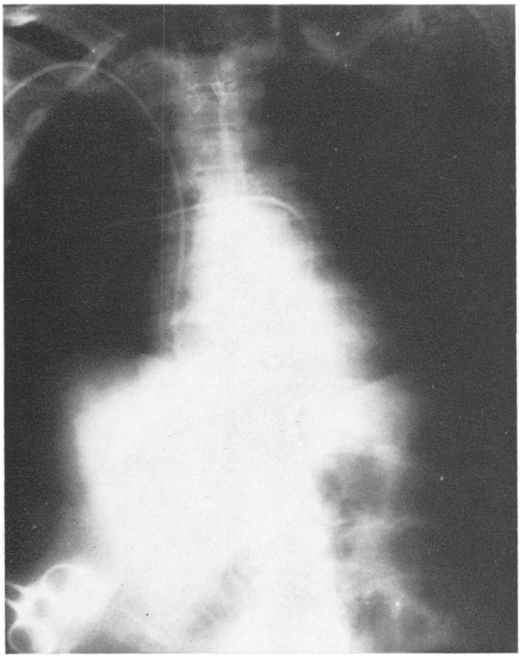

FIG. 4. PAP catheter placement verified by postinsertion chest film.

over the Bandaid which covers the entrance of the catheter into the skin. When this is done and the bleeding is still not stopped, local pressure for 30 minutes by an aide or the patient himself may be satisfactory. If not, a 3-inch ace bandage is wrapped from the supraclavicular fossa to the opposite axilla and utilized in this fashion. We have had one serious internal hemorrhage in our series.

Immediately after insertion of the catheter and connection of the line, the patient is taken out of Trendelenberg position and placed in semi-Fowler position. He should remain in this position for 30 minutes following insertion of the catheter after which normal activities are resumed.

We have found that it is important when x-raying the patient immediately postinsertion of the catheter for position, to have this done portably. If this patient must go to any area for studies or therapy, he should be accompanied by an aid whose sole job is to keep the line open. The catheter should be flushed vigorously with heparin, procaine or lidocaine solution when the dressings are completely changed every 3 to 4 days. A sterile Bandaid with triple antibiotic ointment should be placed over the cutaneous entrance of the catheter and changed daily. The catheter tip is routinely cultured. We add 1,000 U heparin, 8 cc. of bicarbonate (1 mEq./cc.) and 5 cc. lidocaine 1% to each liter of fluid the patient receives. There has been an extremely low incidence of catheter contamination after removal. Pressure for 10 minutes following withdrawal of the catheter is all that is necessary. This is followed by application of a Bandaid in a firm fashion with triple antibiotic ointment.

It is good practice if the patient has a good lung and a bad lung to attempt to place the catheter line on the side of the bad lung first.

Blood may be aspirated and hypertonic, irritating solutions may be given through the subclavian catheter. Thrombosis or other sequelae are rarely seen because of dilution. No matter where the catheter is placed, however, it is mandatory to confirm by x-ray, at the time of insertion, the position that it finally assumes (Fig. 4).

Meticulous care of the catheter site is mandatory and is the only means of preventing invasive infections and systemic sepsis. If this is carried out, catheters may be left in 30 to 60 days without difficulty.

Misinterpretation

When using CVP as a guide many mitigating factors must be kept in mind. Most serious of these is failure to appreciate the "lag phenomena" and to overhydrate the patient by administering fluid too fast.[2] This problem is avoided by giving fluid in 200 to 300 ml. increments and waiting for the ventricles to assume the most efficient ventricular function curve for them.

Other important factors are the use of trends rather than single values, and the measurement of CVP at the same level on the patient with the patient in the same position. Changes in intrathoracic pressure such as Valsalva maneuvers or coughing by the patient causes inaccuracies as will pneumothorax or hemothorax. Pulmonary fibrosis and pulmonary embolus are other causes of false CVP elevation as far as total body fluid need is concerned, although in this example right ventricular failure is accurately reflected.

Vasoactive drugs, especially vasoconstrictors, cause venospasm and can elevate the CVP 10 mm. Hg or more when actually volume is needed. A typical example of this is the patient given increasing doses of pressor due to persistently dropping blood pressure in whom fluids are restricted due to an elevated CVP and low urine output.[3] Many of these patients respond to cautious fluid administration and cessation of vasopressors.

Mechanical increases in pressure due to ventilators, endotracheal anesthesia, or occlusion of the catheter by thrombus or kink must be watched for as well. The column of fluid should fall freely in the manometer during measurement or mechanical flaws can be anticipated.

Mediastinal compression due to fluid extravasation is another pitfall to keep in mind.

Complications

Complications reported are many and often bizzare. Hence the need for the procedure must be weighed against any potential hazzard to the patient. Most common in our experience are hematoma formation followed by catheter occlusion with thrombus. Failure to insert the catheter ranks next; while pneumothorax, hemothorax, and local infection have been seen but are infrequent. Systemic sepsis has occurred in several patients, the organism usually being *Candida albicans*. The one mortality in our series was from an air embolus. Anyone undertaking this procedure must be prepared to prevent this problem and also institute immediate therapy if the complication should occur. Other reported complications such as catheter embolus have not occurred in our series. The overall problems of complications and their avoidance is the topic of a subsequent communciation. Complications are frequent enough to vindicate weighing the use of the method in each individual patient and to dictate a list of indications for its use.

TABLE 2. *Comparing 3 Parameters in 116 Patients with Shock or Major Surgery*

	CVP	PAP	PCWP
27	+	+	+
13	+	+	−
76	−	+	+

Key: + means elevated.
− means normal or low.

This demonstrates that the majority of patients in this selected series required PA catheters to determine their real volume needs.

Indications

Indications for central venous catheterization include: (1) monitoring central venous pressure which should be done in any critically ill patient, (2) any patient receiving long-term parenteral fluid therapy, (3) hyperalimentation, (4) prolonged antibiotic administration, as for subacute bacterial endocarditis, or chemotherapy, (5) any time an intravenous line will be necessary for more than 3 or 4 days and the administration of fluids is critically important, (6) along with PAP catheter in myocardial infarctions with shock, (7) multiple system injury patients, and (8) open-heart surgery.

Pulmonary Artery Pressure

Pulmonary artery pressure is an adjunct which is necessary in addition to CVP in a selected group of patients (Table 2). In this group we have found, early in the course of the problem, that CVP does not reflect total cardiac competence because there is unequal action and efficiency in the

TABLE 3. *Complications of PAP*

1. Knotted catheter	1
2. Local infection	4
3. Balloon rupture	2
4. Cardiac perforation	1
5. Arrythmia	4
6. Hematoma	2
	14*

* 12% Complication rate.
Listed complications of pulmonary artery insertion. Note that all but a few are minor in nature.

right and left ventricle. A large portion of this group of patients showed pulmonary capillary wedge pressures differing from CVP and early rising pulmonary end diastolic pressure before the rise of the CVP.

Pulmonary artery pressure is measured by the technic described by Swan and coworkers.[5] We have catheterized 116 pateints of whom the most recent 64 have been catheterized by the flow-directed Swan-Ganz pulmonary artery catheter. The technic of Swan *et al.* is effective and we have utilized a pressure monitor for the position monitoring of the catheter. This can also be done by ECG monitoring (Table 5). Its placement is again checked by x-ray verification following insertion. We use a counter incision to insert the catheter through a needle tract previously made by a #12 needle in the skin away from the site of venasection. Triple antibiotic ointment is applied to the catheter-cutaneous site and the cutdown incision. Catheter patency is maintained with a micro-infusion pump * or a dilute heparin drip. It cannot be used for administration of fluids because of the small diameter of its lumen. Complications such as rupture of the balloon, knotting of the catheter, misplacement, cardiac arrhythmias, and thrombus formation have been encountered by various authors. In addition to this, perforation of the pulmonary artery and right ventricle have been reported by catheterization technics of the right ventricle and central venous system. However, the morbidity and mortality of the technic must be weighed against the necessity for performing the procedure and the value of the information that is obtained in this fashion. These catheters have been left in place for a duration of 72 hours by us without difficulty. Others have left them longer.[5] The advantages of the Swan-Ganz catheter are the ease of insertion, safety, and the ability to monitor multiple parameters with this method. The drawbacks of the technic are (1) the danger of injecting wide ranges of osmolar and different pH solutions into the central pulmonary system, (2) the difficulty in determining measurements with hypoxemia and acidosis which cause pulmonary vasoconstriction, (3) eventual clotting of the catheter, possible valvular damage and thrombosis must be considered, and (4) there may be local infection at the entrance site of the catheter but this has been obviated by us to a great extent by

TABLE 4. *Type Patients Needing PAP*

1. Cardiac Pump Failure
   a. myocardial infarct
   b. congestive heart failure
2. Major Trauma
   a. need to give large volumes rapidly
   b. burns
   c. massive abdominal tumor resection
3. Progressive Pulmonary Insufficiency
4. Major Fluid and Electrolyte Imbalance
   a. intestinal obstruction
   b. renal failure
   c. cirrhosis, ascites, portal hypertension
   d. dissecting aortic aneurysms
5. Systemic Sepsis
   a. peritonitis
   b. septicemia
6. Pulmonary Embolus
7. Pulmonary Fibrosis

This outlines the type of patient with shock or major illness that needs pulmonary artery catheterization.

* Chronfusor, United States Catheter, Inc., Glens Falls, N. Y.

the use of the counter incision. We have had a total of 14 complications of which one was serious. None of the complications led to the death of any patient (Table 3).

It is necessary to resort to PAP on selected occasions because of the right and left ventricles which function in series as pumps. The output from both the right and left ventricles is not always the same. The variation in the functional state of the two ventricles and the output pressures with which they must contend signifies that the ventricular outputs must be balanced by changing either the force and velocity relationships which reflect myocardial contractility or by the Starling mechanism which relates to the energy of contraction and the length of muscle fibers. Normally right and left ventricular function curves are similar in shape and small changes in the filling pressure can produce large increments in stroke work. In the absence of valvular heart disease, atrial pressure and stroke work of each ventricle is consistent in its relationship. However, the right atrial pressure and the left ventricular stroke work are not always equal. Significant alterations in the circulatory state cause differences in the ventricular function curves in the two areas. Central venous pressure monitoring only reflects right ventricular function and left atrial pressure or its reflected PCWP must be used to assess left ventricular function. It is because of this that the diastolic pulmonary artery pressure or PCWP are necessary to clinically assess the left ventricular function.

The advantage of this catheter is the mean pulmonary artery pressure which may be recorded as well as end diastolic pulmonary artery pressure. This correlates better with the status of the left ventricular function than does CVP. In our series the most accurate correlation between ventricular function and fluid need was that of pulmonary capillary wedge pressure (Table 2). When pulmonary capillary wedge pressure is greater than 16 to 18 cm. of water it is good evidence of left ventricular failure, in our experience. This often has preceded right ventricular failure by 30 to 60 minutes. Another advantage of the Swan-Ganz catheter is that it bypasses any intrinsic right ventricular disease and gives a direct measurement of the left ventricle's need for further volume. Mixed venous blood, analysis for pH and P_{O_2} are also good for early prediction of progressive pulmonary insufficiency. The decrease in the two parameters early in the presence of catastrophic illness correlates with the onset of progressive pulmonary insufficiency. However, this is less useful when the disease progresses and increased pulmonary vascular resistance secondary to acidosis and hypoxemia is a factor causing pulmonary artery pressure to increase. Finally, pulmonary angiograms may be performed through this catheter and selective right and left pulmonary angiograms may be helpful in deciding whether or not a major pulmonary embolus has occurred. A special #7 French catheter is now made for this purpose.

The criteria for use of the catheter is the magnitude of the procedure and the limited time period in which it may be inserted (Table 4). The possibility of potential local and systemic infection are important

TABLE 5. *Methods of Detecting Position*

1. EKG Method
   a. attach 3 leads and precordial leads to saline filled catheter
   b. peripheral EKG goes to large P waves in atrium
   c. Right ventricular complexes in ventricle
   d. Normal EKG in pulmonary artery
2. Pressure Method
   a. higher peripheral pressure
   b. lower toward atrium
   c. higher and pulsatile in ventricle
   d. lower pulse wave form in pulmonary artery

The two ways to monitor catheter position during placement are outlined. X-ray verification of position is necessary following insertion.

considerations. The small lumen of the catheter damps the pressure which is obtained and it has been suggested by some authors that electronic determination may be superior to manometric determination. The small lumen of the catheter also precludes the use of this portal for fluid administration. The necessity for a venesection, the problem of arrhythmias and valvular damage are also considerations in utilizing this technic.

This catheter has been used by us mainly as a pressure monitor and for the obtaining of mixed venous gases. It is much more sensitive than the central venous pressure monitoring, but it is only indicated in critically ill patients. X-ray confirmation should be obtained after the catheter has been inserted and the operator is content with its placement based on pressure or ECG readings (Fig. 4, Table 5). If the pulmonary artery pressure increases and central venous pressure remains normal, isolated or pure left-sided failure has been the cause in our series.

To summarize, the pulmonary artery can indicate earlier if an excessive fluid load is present by an increase in pulmonary capillary wedge pressure. The right heart in the meantime may compensate for this increased load and reflect only a normal central venous pressure. When dynamic equilibrium is obtained and the right ventricle works at top capacity the central venous pressure will remain low. However, after a short period a decrease in efficiency occurs, right ventricular failure ensues and the central venous pressure then elevates. A rising pulmonary artery end diastolic pressure or pulmonary capillary wedge pressure is a clue to early reduction of fluid administration and the fact that early hypervolemia may be present.

Summary

The central venous catheter should be used in any situation which requires monitoring and fluid administration. It must be remembered that accurate readings assume equal ventricular functional efficiency and constant site of measurement. The supraclavicular technic is the best approach and is associated with the fewest problems in experienced hands. It can be left in place almost indefinitely with the smallest hazard of sepsis.

If the ventricles are suspected of malfunction or the indications stated in Table 4 are present, a PA catheter is used. This should be used in any patient in shock or with major surgical trauma, either spontaneous or iatrogenic. This provides mean PAP, end diastolic PAP, pulmonary capillary wedge pressures, central venous blood for P_{O_2} and pH as well as potential for pulmonary angiography. Pulmonary edema is rare with pulmonary capillary wedge pressures less than 15 mm Hg.

Both procedures have morbidity and potential mortality and as in major diagnostic modality, their use must be guided by the operator's ability and experience. In addition the potential benefits of the measure must be weighed against the inherent potential hazards associated with it. We believe the CVP and PAP alone and in combination can be extremely beneficial in the management of critically or chronically ill patients.

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Discussion

Dr. Curtis Price Artz (Charleston): We all depend upon central venous pressure as a means of insurance that we are not overloading the heart. It is a relatively simple technic in most hands.

There may be two areas of difficulty in central venous pressure monitoring. First, unless one checks the extent to which the central venous catheter goes down the vena cava, it might go into the right side of the heart and erode the wall of the auricle. This will lead to cardiac tamponade and death.

Second, in our institution the residents are not taught to do subclavicular or supraclavicular sticks. We have tried it, but our complication rate has been too high for something so simple as an intravenous infusion.

Maybe after you have done hundreds you are adept and probably can perform a supraclavicular stick without complication. But to teach the resident who is going out into the average hospital and will do these procedures only occasionally seems wrong. I feel it is wise to teach a safe technic, which is to go into the antecubital fossa.

As far as pulmonary artery pressure is concerned, I think we will begin using these in our intensive care unit, and I can see how this will be of tremendous value.

Dr. Paul M. James, Jr. (Closing): I would like to say that the complications we have encountered are the subject of another entire paper. I do want to emphasize, though, that on peripheral CVP's there are equally as many complications, although I heartily agree that in unpracticed hands this is probably a safer technic.

In closing, I would just like to emphasize several things. First of all, the supraclavicular technic has has been safer than the subclavicular technic in our hands, primarily because of the decrease in the number of pneumothoraces. One way to get practice at this in a rather inexpensive manner to the patient is to look at the supraclavicular fossa during a supraclavicular node biopsy or a scalene node biopsy.

The second thing would be to look at the cadavers in the anatomy lab and see how the vessels are located there which is a big help in seeing just how this vessel lies. By aiming at the confluence, we have been able to relatively limit the number of complications, and we have had over 50 people involved in doing the procedure at this point.

I would like to emphasize that the pulmonary artery pressure, as D. Myers said, is determined in critically ill patients, in the massively injured and in patients who have been in shock. This is based on the fact that biventricular, equal function of the ventricles is not necessarily true in these patients, and therefore it is necessary to know what the right heart and the left heart is doing, to keep from getting burned.

Finally, in order to realize your own mistakes and to prevent accumulating a large series of complications, a periodic inventory of your performance is critically important in evaluating this effort. I agree heartily again with Dr. Artz that we should not be sending people out who do not know how to do this procedure. We have tried to describe the technic exactly in the paper, but beyond this I would say that you should see it done first hand before you attempt it.